Flexible Power 90W to 120W ArF Immersion Light Source for Future Semiconductor Lithography

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ABSTRACT

Semiconductor market demand for improved performance at lower cost continues to drive enhancements in excimer light source technologies. Increased output power, reduced variability in key light source parameters, and improved beam stability are required of the light source to support immersion lithography, multi-patterning, and 450mm wafer applications in high volume semiconductor manufacturing. To support future scanner needs, Cymer conducted a technology demonstration program to evaluate the design elements for a 120W ArFi light source. The program was based on the 90W XLR 600ix platform, and included rapid power switching between 90W and 120W modes to potentially support lot-to-lot changes in desired power. The 120W requirements also included improved beam stability in an exposure window conditionally reduced by 20%. The 120W output power is achieved by efficiency gains in system design, keeping system input power at the same level as the 90W XLR 600ix. To assess system to system variability, detailed system testing was conducted from 90W – 120W with reproducible results.

1. INTRODUCTION

Cymer first introduced the XLR 500i light source with master oscillator – power regenerative amplifier (MOPRA) architecture in 2007 to meet light source requirements primarily on cost-of-ownership and dose stability [1]. The 6000Hz, 60W XLR 500i enabled improved resolution and critical dimension (CD) control at high throughput, with reduced operating costs. Subsequent light source models offered by Cymer and based on the dual-chamber MOPRA architecture, include the XLR 600i introduced in 2008 [2], and the XLR 600ix introduced in 2009 [3]. These light sources enabled further improvements in the resolution of semiconductor lithography past the 32nm node, through the use of double patterning and the extension of numerical aperture to 1.3 and beyond. Power output of the XLR 600ix increased by 30% from the XLR 500i to 90W, and beam stability requirements were tightened to enable scanner improvements in focus and overlay associated with multiple patterning. The XLR 600ix light source has demonstrated excellent system performance stability over a 30 billion pulse lifetest [4], and over 200 systems in the field supporting memory, logic, and foundry applications have demonstrated stable and reliable performance with greater than 99.6% uptime [5].

To support reductions in critical dimension and a transition to 450mm wafer size, the semiconductor roadmap demands further improvements in scanner resolution and throughput, which in turn places requirements on the light source for higher output power and tighter beam stability in a reduced exposure window. Furthermore, the flexibility in scanner operating parameters demanded by multi-patterning techniques, creates requirements on the light source to quickly switch between and control beam stability at different wavelengths, bandwidths, and pulse energies. To prepare for future scanner requirements, Cymer has conducted a technology demonstration program to evaluate the design elements for a 120W ArFi light source. The program was based on the 90W XLR 600ix platform, and included rapid power switching between 90W and 120W modes to potentially support lot-to-lot changes in desired power. Three 120W ArFi demonstration units were built and tested, and were identical in configuration. The increase in output power from 90W to 120W was realized by utilizing efficiency gains in

multiple system components in a manner that does not increase the system input power. All dose stability and wavelength stability metrics for the 120W ArFi demonstrators are processed in an exposure window reduced by 20% as compared to the XLR 600ix, reflecting the higher stage speed expected in future scanners. To accommodate diverse lithography process conditions, the light source output power, wavelength, spectral bandwidth, and duty cycle can all be varied over a wide range.

This manuscript reports on the specific advancements in technology that enable stable system performance of the 120W ArFi demonstrators. Data will be shown for three systems that were tested to clarify the system to system variation that can be expected when operating at higher power. These data will include light source performance metrics in a test meant to simulate wafer exposure firing patterns in 90W and 120W modes, and in a long-duration stress test meant to characterize performance across the vast majority of possible firing modes.

2. TECHNOLOGY ADVANCEMENTS ENABLING FLEXIBLE 90W TO 120W OPERATION

The output of the 120W ArFi light source demonstrators will be pulses of light with temporal duration between 100 and 150ns, at a repetition rate at or less than 6000Hz. For continuous firing at the maximum repetition rate, 15mJ pulse energy results in 90W output power, and 20mJ pulse energy results in 120W output power. The 120W ArFi light source is capable of firing at any pulse energy between and including 11.7mJ to 23.0mJ. The central wavelength of the light source is 193.3680nm, and a typical spectral bandwidth is 300fm using the integral-95% definition (hereafter referred to as 'E95% bandwidth'). The central wavelength and E95% bandwidth of the 120W ArFi light source are actively controlled to support light source requirements derived from the focus, overlay, and CD control requirements of the scanner. Spectral parameters are also tunable to support precise matching of the light source spectrum to diverse lithographic tools. The size of the output beam, as defined within the full-width-5% of the near-field intensity distribution, is 12mm by 12mm, divergence in two axes is less than 2mrad, and the peak beam energy density is less than $40mJ/cm^2$ for all operating conditions up to 120W.

The system architecture of the 120W ArFi light source demonstrators is a dual-chamber configuration based on the field-proven XLR 600ix, to take advantage of high uptime demonstrated by over 200 XLR 600ix sources operating in the field [5]. A simplified diagram of the light source with some core modules identified is shown in Figure 1. The master-oscillator subsystem (module 2) creates a low energy pulse of light with short temporal duration (10s of ns) and precise control of spectral parameters. This light pulse traverses relay optics and metrology modules, then enters the power regenerative amplifier (module 3). The ring optics (module 4) send the light pulse through many passes of the power regenerative amplifier as energy of the light pulse is amplified consistent with desired light source output power. Finally, the temporal duration of the light pulse is increased by the optical pulse stretcher (module 5) in order to reduce peak irradiance of the beam, thereby extending lifetime of scanner optics. Driving a precisely-timed electrical discharge in both the master-oscillator and in the power regenerative amplifier to provide laser gain, are a series of solid-state pulsed power modules (module 1).

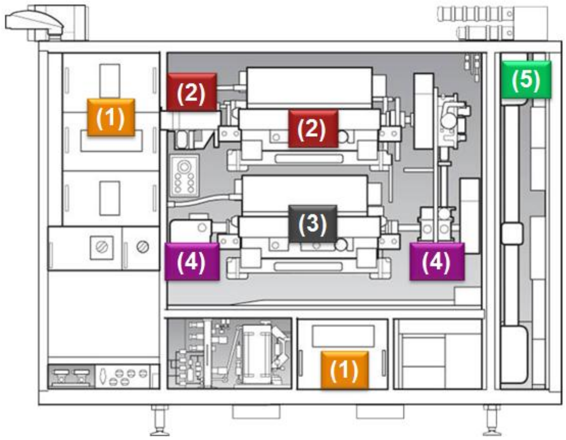

Figure 1. Diagram of the XLR 660ix / 120W ArFi light source with some core modules labeled: (1) solid-state pulsed power modules, (2) master-oscillator subsystem, (3) power regenerative amplifier, (4) ring optics, (5) optical pulse stretcher.

Most of the XLR 600ix core modules and their operating conditions see no change from the XLR 600ix to the 120W ArFi light source. All of the solid-state pulsed power modules (module 1 in Figure 1) and their operating conditions are unchanged in the 120W ArFi light source. The master-oscillator subsystem (module 2) is also unchanged in design and operating conditions. The power regenerative amplifier is largely based on the design used in the XLR 600ix, with a few key improvements that enable reduced optical losses and increased laser gain. The ring optics are also optimized for reduced optical losses, and additional improvements were made to ensure beam stability from 90W to 120W. Fast power switching on lot-to-lot timescales is achieved by the automated use of intracavity attenuating elements in the ring optics. Additionally, improvements were made to the optical pulse stretcher (module 5) to ensure beam stability at the increased thermal load of the 120W light source.

Inputs to the light source from facilities include cooling water, electrical power, optics purge gas, and the chamber gas mixture. From the point-of-view of facilities input to the light source, there is no difference between the XLR 600ix light source and the 120W ArFi light source. All water, electrical, purge gas, and chamber gas requirements are unchanged. The reduced optical losses and increased laser gain of the power regenerative amplifier subsystem (modules 3 and 4) enable the 30% increase in output power with no impact to system input power, i.e., the wall-plug efficiency of the 120W ArFi light source is 30% higher as compared to the XLR 600ix. Figure 2 quantifies the increase in stable 193nm output power per kilowatt of input power over three generations of Cymer light source, up to the 120W ArFi tool.

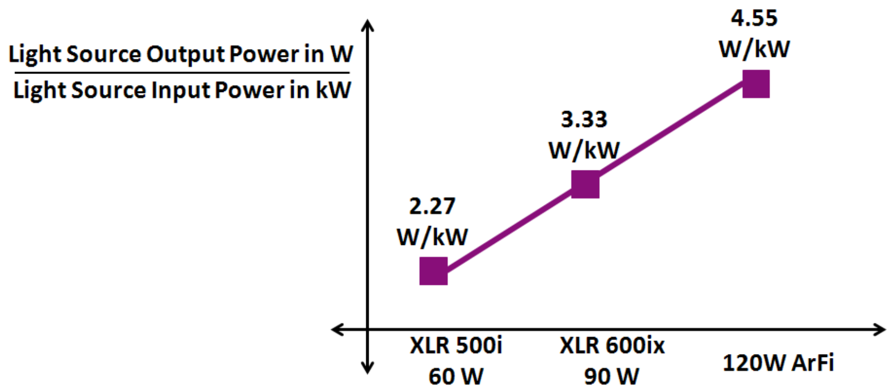

Figure 2. Wall-plug efficiency, as measured at Cymer San Diego, over three generations of Cymer light source.

3. SYSTEM PERFORMANCE DATA FOR THREE LIGHT SOURCES

Three 120W ArFi light sources were built in 2013 as a technology demonstration. A suite of extensive design validation tests was executed and passed for each 120W ArFi light source. This test suite fires the light source in the vast majority of its possible use cases, and monitors all performance metrics of concern to chipmakers on the equivalent of a die-by-die basis. Additional tests were run to validate the design intent of all changes in the 120W ArFi design from the XLR 600ix, and results validated the efficacy of improvements made to the power regenerative amplifier and ring optics to improve efficiency and allow lot-to-lot power switching.

Data from two tests within this extensive test suite will be presented. Data will be shown from the *Wafer Simulation Test*, designed to replicate firing patterns used in 90W and 120W wafer-exposure modes, and also to monitor system performance across lot-to-lot power switching. Data is also presented from the *20-Hour Endurance Test*, meant to fire the light source in the majority of its possible use cases while monitoring all light source performance metrics.

Dose stability is a measure of the output power stability, used to ensure uniform irradiation of the photo-resist, and is shown in Figure 3 as measured in the wafer simulation test for three Cymer 120W ArFi light sources. The test includes three 90W firing modes, and three 120W firing modes, with a power switch executed after each mode. The data demonstrate consistent system performance for three light sources, with system-to-system variability almost within the die-to-die variability for an individual light source. Whereas the data of Figure 3 show system performance across a few simulated wafer exposure modes lasting about 3 minutes, the data of Figure 4 show data across 10 hours of firing in 90W modes, then 10 hours of firing in 120W modes. Each trace in Figure 4 represents approximately 70 thousand data points, where each data point represents a light source performance metric derived from a single burst fired by the light source (total number of light pulses in the 20-hour test is approximately 70 million). The 90W and 120W modes of the 20-hour test are nominal power levels; the actual power levels depend on the light source pulse energy and duty cycle. The 20-hour test uses pulse energies from 11.7mJ to 17.3mJ at the 90W mode, and from 15.5mJ to 23.0mJ at the 120W mode, demonstrating the ability of the light source to fire between 90W and 120W, and to fire at overlapping energy targets in both nominal power modes.

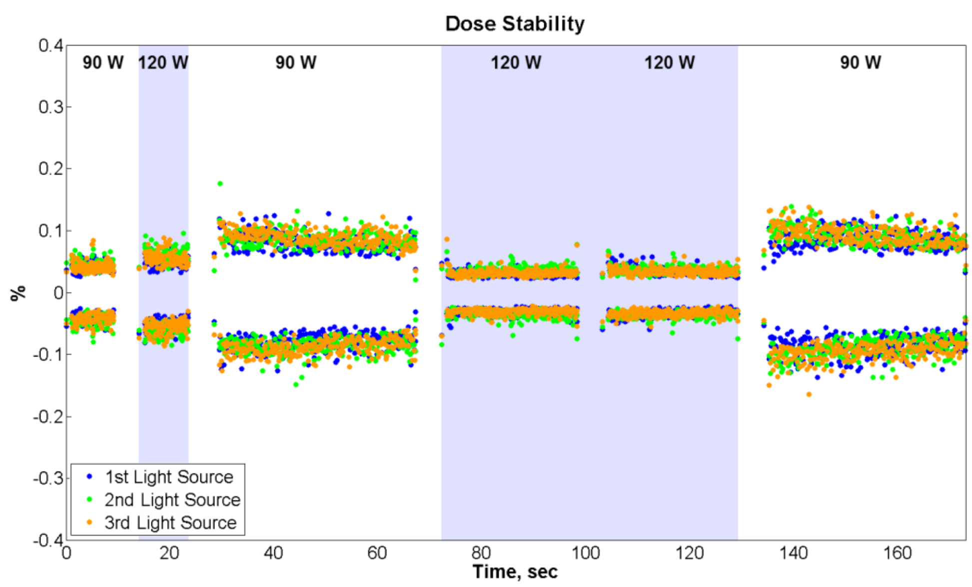

Figure 3. Dose stability of three light sources in the Wafer Simulation Test, demonstrating stable and consistent system performance for 90W and 120W power modes across lot-to-lot power switching.

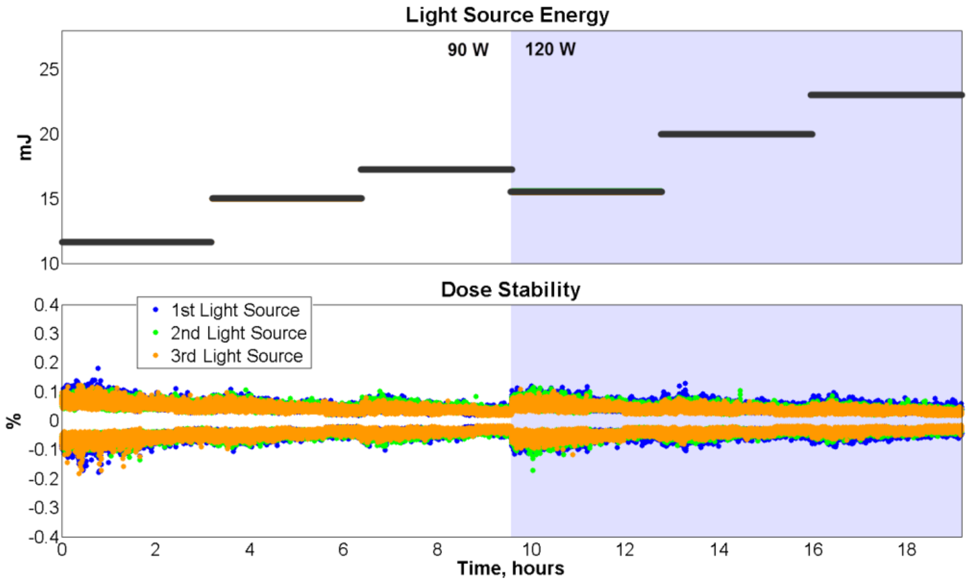

Figure 4. Light source energy and dose stability of three light sources in the 20-Hour Endurance Test, demonstrating stable and consistent system performance for 90W and 120W power modes.

The wavelength and E95% bandwidth of the 120W ArFi light source are actively controlled in order to support anticipated focus, overlay, and CD control requirements of the scanner. Figure 5 shows wavelength and bandwidth stability data for three light sources collected in the wafer simulation test; Figure 6 shows the same for data collected in the 20-hour endurance test. For both cases, multiple light sources demonstrate stable and consistent wavelength and bandwidth system performance in 90W and 120W modes.

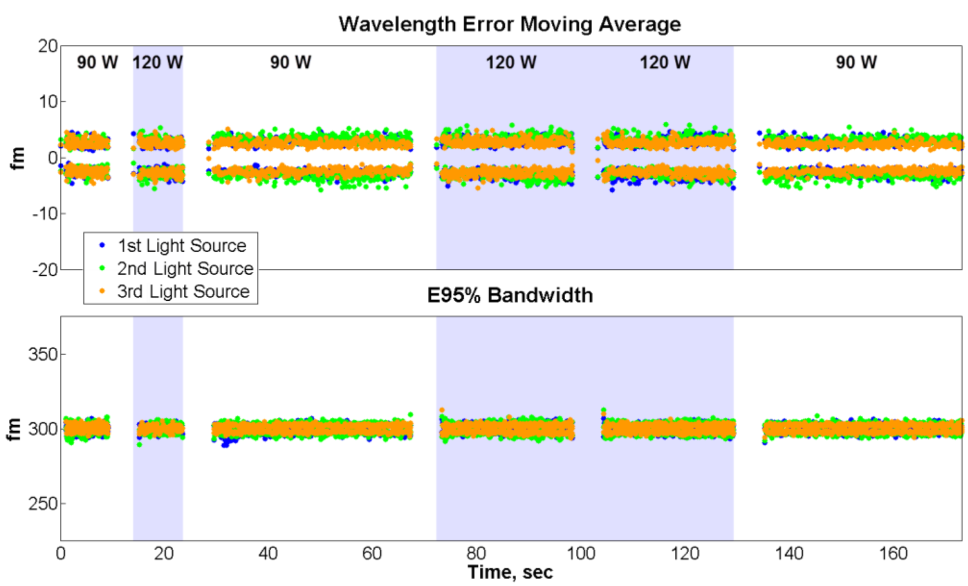

Figure 5. Wavelength and bandwidth stability for three systems in the Wafer Simulation Test, demonstrating stable and consistent system performance for 90W and 120W power modes across lot-to-lot power switching.

Figure 6. Wavelength and bandwidth stability for three systems in the 20-Hour Endurance Test, demonstrating stable and consistent system performance for 90W and 120W power modes.

There are several additional light source performance metrics of concern to chipmakers in addition to dose stability, wavelength stability, and E95% bandwidth stability shown in the previous figures for three 120W ArFi systems. A previous article on the 120W ArFi light source includes data to demonstrate excellent beam polarization at the highest duty cycle and power output expected in field use [6]. This previous article also demonstrates stable beam divergence, beam width, beam pointing stability, and beam position stability up to 120W. These parameters were also monitored during the extensive design validation testing for three 120W ArFi systems, demonstrating stable and consistent performance up to 120W. For example, figure 7 shows beam divergence and pointing stability in two axes for three 120W ArFi systems in the Wafer Simulation Test, and figure 8 shows beam energy density in the 20-Hour Endurance Test as measured by two-dimensional beam imaging metrology.

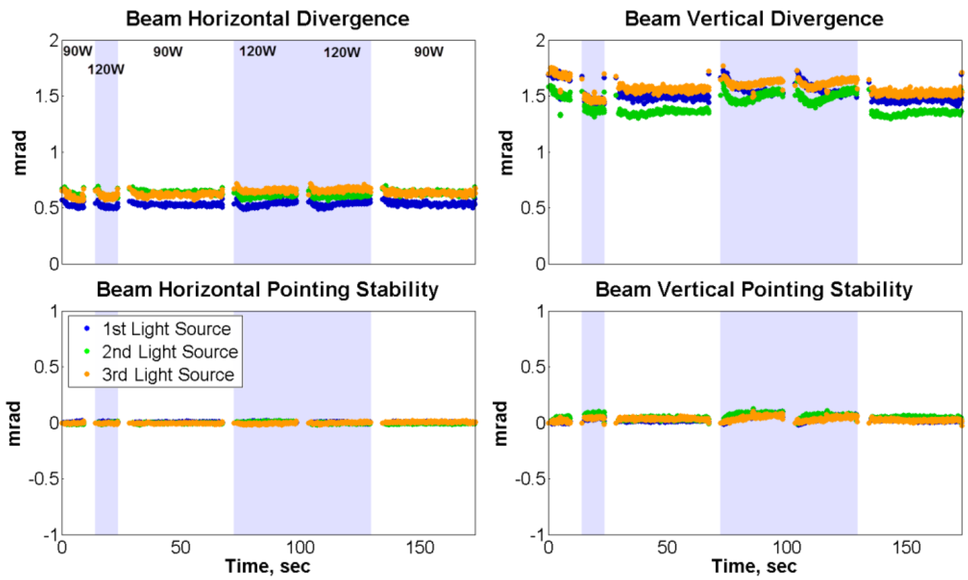

Figure 7. Beam divergence and pointing stability for three systems in the Wafer Simulation Test, demonstrating stable and consistent system performance for 90W and 120W power modes across lot-to-lot power switching.

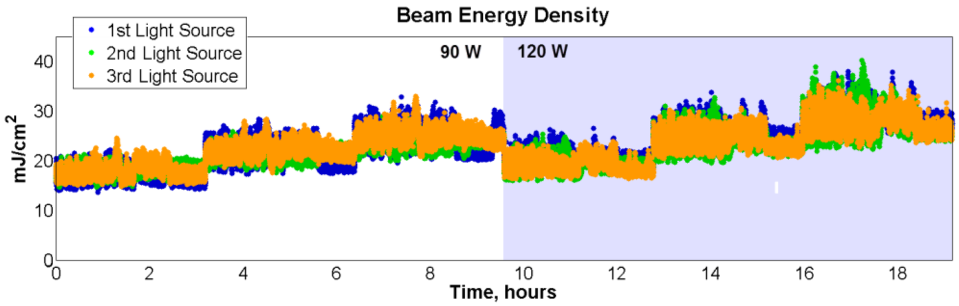

Figure 8. Beam energy density as measured by two-dimensional beam imaging in the 20-Hour Endurance Test, demonstrating stable and consistent system performance for 90W and 120W power modes.

4. SUMMARY AND CONCLUSIONS

Cymer has conducted a technology demonstration program to assess the key performance capabilities of a 120W ArFi light source to meet anticipated semiconductor industry requirements. Higher light source power is expected to be a future requirement to support 450mm wafer applications, high dose applications, and also high-throughput immersion and multiple-patterning applications. Flexible 90W to 120W output power with lot-to-lot power switching will enable optimized dose for a variety of lithography processes. As part of the technology program, three 120W demonstration units were built and tested. The test results indicated that the key optical parameters were stable across different power levels, and showed consistent performance across the multiple units. In addition, the demonstration units confirmed that wall-plug efficiency of the 120W lightsource was increased by 30% compared to the current XLR 600ix model, so that increased output power does not require any additional facilities power.

5. REFERENCES

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